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STUDIES ON THE FAUNA OF SOME THERMAL SPRINGS IN THE DUTCH EAST INDIES

By Charles T. Brues

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Introduction

The writer first became interested in the insect and other animal life of hot springs on the occasion of a visit to the Yellowstone National Park in 1923. At that time he secured a small number of specimens together with data on their distribution in the thermal waters of this remarkable area, and published an account of his observations shortly afterward (Brues '24). Twice later he had the opportunity to visit a considerable number of the numerous hot springs that exist in several of our western states, notably Nevada, Utah, and California, and to make further collections in Yellowstone Park. The results of these later studies are embodied in two other publications (Brues '28 and '32) which include also a general account of the occurrence of animal life in thermal waters and the adaptations of aquatic organisms to abnormally warm environments.

Previous to this time, very few biologists had made more than incidental observations on animal life in thermal waters. Unfortunately some of these were rather carelessly made and led to highly erroneous conclusions concerning the temperature relations of a number of different forms. As I have considered these early publications previously they require no further comment at the present time. Since then several other zoologists, notably Ciofalo in Sicily and Tuxen in Iceland, have turned their attention to the fauna of hot springs while Thienemann and his associates have made numerous observations on the thermal fauna in connection with their more general limnological investigations.

Aside from material gathered by these last named workers which has been dealt with by several specialists in some recent volumes of the Archiv für Hydrobiologie under the title of "Tropische Binnengewässer" a knowledge of the fauna of thermal springs in the tropics is very scanty.

It was therefore with great satisfaction that I embraced a recent opportunity to visit, in company with my wife, several of the volcanic islands in the Dutch East Indies where we were able to collect material, and to make observations on a number of hot springs.

We proceeded first to Sumatra in May 1937, remaining until late June with the National Geographic Society-Smithsonian Institution Expedition, which was collecting living animals for the U. S. National Zoological Park under the direction of our good friend, Dr. William M. Mann. In Sumatra we visited several hot springs localities with Dr. and Mrs. Mann. On leaving Sumatra we went by the way of Bali to the northern Celebes to investigate an extensive series of hot springs in the mountains of the

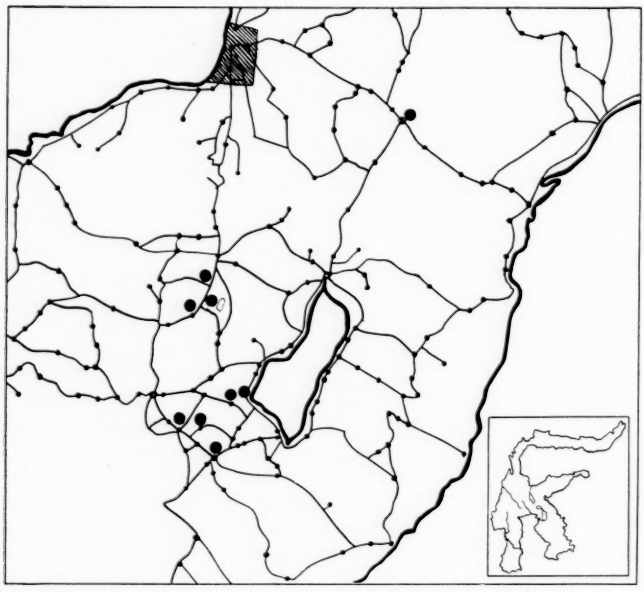

FIGURE 1. Sketch map of area surrounding Menado and Lake Tondano, showing location of hot springs. Each spring is indicated by a large black dot, the small towns by a small dot. On inset map of Celebes at the lower right, this area near the extreme northeastern end of the island.

Province of Minahasa which lies at the extreme northeast end of this island. Returning southward to eastern Java in August we visited a number of the numerous thermal springs that occur along the central mountain ridges which extend almost the whole length of the island.

Excellent roads are maintained by the Dutch Colonial government generally throughout Java, in most portions of Sumatra, in a part of Bali and in several sections of the Celebes, so that extensive travel by automobile is both convenient and expeditious. In this way we traveled some 4,000 miles during the course of our journey.

Before dealing with their fauna, it is necessary to present a brief account of the location and general characteristics of the several thermal springs or groups of springs which we were able to examine. They are in general very much like those of temperate North America both in appearance and physiographic features. A most conspicuous difference is, of course, the tropical flora that surrounds them and the fact they are in regions of heavy rainfall and luxuriant vegetation unlike most of the hot springs of the western United States which commonly arise in arid or desert portions of the country.

DESCRIPTIVE LIST OF HOT SPRINGS STUDIED

CELEBES

All of the hot springs which we visited on this island are in the extreme northeastern part, known as the Province of Minahasa. At this end the island is very narrow, the irregular north and south coasts separated by a distance of from 30 to 50 kilometers. Menado, the principal city and seaport is near the eastern end, on the north coast and the springs are grouped in the central highlands (Fig. 1) westward from Lake Tondano which is easily reached from Menado by automobile. This is an old crater lake at an elevation of about 2,300 feet and the springs are all within a few kilometers of its western shore.

Nearly a century ago Alfred Russell Wallace and Albert P. Bickmore visited this region and gave the first descriptions of several of these hot springs in the accounts of their travels in the Malay Archipelago. There were no accurate maps at that time, although Wallace gives a very good sketch map showing the springs he visited and we have been able to recognize them with certainty. It has thus been possible to make some interesting comparisons which show

what changes have taken place over a long period of time.

Paso Hot Springs

This group is nearest to Lake Tondano in the village of Paso which lies close to the southern third of the western shore of the lake. The springs extend for a distance of several hundred yards near the main street of the town, more or less concealed by dwellings. One spring, toward Lake Tondano from the road, includes several pools, two of them very hot and partly utilized by bath-houses built near them. Another one with a temperature of only 34° is densely covered with duckweed. Across the road is another at 47° which serves as a native place for bathing and washing clothes. This flows down the road and under it into a rice field, there it joins a warm stream that parallels the road on the east side. In this overflow the water cools to 36° and 37° in two pools where we obtained insects and snails. There is no obvious deposit about these springs which are of nearly neutral reaction (pH 7.3).

Langoan Hot Springs

These are evidently the small remains of a once very extensive series of springs near the village of Langoan, about 11 kilometers southwest of the southern end of Lake Tondano. The only active spring is a large pool about 25 feet in diameter. It is surrounded by a natural sinter rim, but an opening in this has been plugged with concrete to increase its storage capacity and incidentally to ruin its appearance since the water-level has been raised a few inches, leaving the rim visible but covered. The flow is considerable with a temperature of 70° in the pool. This cools off where the water is led off through bamboo conduits into several pools, having cooled down to 39°, and into some bath-houses. The pools are artificially formed by the piling up of much soil, tufa, etc. The fauna includes several species of insects and abundant small frogs. Above the present spring there is a large quarry in the side of a hill where the pure white, stony sinter is mined in large quantities and chiseled into gate posts and tombstones. These may be seen in numbers scattered through the nearby towns and villages although the stone is very soft and weathers rapidly. The tufa deposits extend in the other direction toward Langoan as they are exposed for some distance along the road leading to the spring. This is evidently a permanent spring; in 1865 Bickmore visited it and found the temperature to be 78°; only eight degrees higher than at the present time. No other active springs were noted, except one well-like pit, not far away in a native's yard where it was weakly spouting black liquid mud some twenty feet below the surface of the ground. Mud on the surrounding vegetation indicated much more violent eruption during the rainy season which was past at the time of our visit in August.

Airmadidih Spring

This has been previously referred to as a boiling spring, and it apparently was extremely hot as late as 1848 according to Bickmore. When he visited it in 1865, the stream that drained it was cool. It is not far from the main road leading into the village of Airmadidih (sometimes spelled Ayer Madidi) at the base of Mount Klabat. Ascending the road from the river toward the village, it may be reached on the right hand side by a walk of about 100 yards along a bamboo-fenced lane. The spring is a large pool about 30 feet in diameter on a slight slope at the lower edge of a swampy area. It is actively flowing, but scarcely warm (about 30° C.) and is a popular place for bathing and washing clothes. The overflow runs down sharply to find its way eventually into the Tondano river nearby. This is far removed from the several other springs near Lake Tondano as it is 18 kilometers north of the town of Tondano, which lies at the northern tip of the lake.

Takolan Hot Spring

Near Tolok and just beyond the small village of Takolan is a large pool about 15 by 30 feet, with irregular outline. It is about 200 yards from the road at the edge of gently sloping ground, cultivated in maize, and is sunk in dense vegetation consisting of trees, herbs and large coarse grass. It is in ebullition at one spot near the middle, actively steaming and giving off some considerable amount of gas bubbles. At the lower end it runs off into a low flat area as a slowly flowing stream that shortly disappears into the ground at the edge of some rice fields. The water in the run-off is slightly alkaline, with a pH of 7.4 and distinctly murky from whitish clayey material in suspension. Bickmore ('69) who visited this spring in 1865 speaks of the pool as larger, 75 feet in diameter and emitting choking fumes of sulphur. It was evidently larger and more active at that time. Nearby, next to the road is a warm pool with a considerable flow serving to irrigate rice land.

In a straight line this area is only about two kilometers southwest of Paso but there is no direct road between them.

Lake Linau Hot Springs

Lake Linau is a small body of water about one kilometer long and nearly as wide. It is west of Lake Tondano about seven kilometers in a straight line, easily reached by a very poor road leading from Lahendong to Tondangow which crosses the outlet of the lake about one and one-half kilometers out of Lahendong. In certain earlier accounts Lake Linau has been erroneously stated to be in the basin of an extinct crater on the slopes of Mount Klabat, which actually lies far to the northeast. The springs, which are near the middle of the north shore, lie to the left of the road. The water of the lake is of a greenish blue hue, but on the side next to the spring is quite turbid and milky white; between the two halves a sharp line of color demarcation is maintained.

The hot spring is at the top of a gully up a steep slope from the lake. The origin of the warm water is 40–50 feet above the surface of the lake where it arises in a swampy area. The overflow runs down with cascades here and there a foot or so in height forming a stream about twelve inches wide. The bed is lined with clayey mud mixed with small white stones and gravelly material. The water has a temperature of 38° C. and is strongly acid with a pH of less than 3.6. Hidden in the mud of the running stream are countless blood-worms that float down when the mud is disturbed. Along the gully is a gray or white deposit of clayey material that extends for some fifty feet on each side. This becomes very soft and slippery when wet.

Near the lake shore there are noticeable quantities of gas escaping, with a weak sulphurous odor. The surface for a long distance along the shore is soft, covered in places by a harder sinter which gives a hollow sound when tapped, and very close to the edge of the lake we noticed one boiling pool a few inches in diameter. Further around the lake to the north is another swampy thermal area, difficult of access.

The stream which drains Lake Linau descends through a small canyon, on the slopes of which there are outcrops of hot springs deposits indicating much more thermal activity about the lake in times past. Further down this stream are the Leilum Hot Springs next to be described.

Leilum Hot Springs

These are out of Lahendong near the road leading to the village of Leilum. Where the road crosses the stream that drains Lake Linau they are on the left hand side of the road about 100 yards up the stream. At this place there is a considerable amount of deposit on both sides of the bed of the stream where the sides of the valley rise at a moderate slope. On the north bank there is no water but well up the slope are a number of small fumaroles. Across the stream there are a few small bubbling pools, some isolated mud-pots and one large boiling pool. The latter is about fifteen feet in diameter, crater-like in form, surrounded by very dark deposit showing some yellow and contrasting with the older deposits which are almost entirely pale in color. The water in this pool was at that time (early August) five or six feet below the rim of the crater, in very violent ebullition and emitting quantities of steam. Quite probably it may erupt like a geyser during periods of extensive rain. The water in the stream is clear and cold and rushes along a bed strewn with rocks and larger boulders.

Sarongsong Hot Springs

These are west of the northern end of Lake Tondano, about 15 kilometers (*via* Tomohon) to the village of Sarongsong near which the group of springs is located. Ascending a hill beyond the village in a narrow valley to the right is a mass of hot springs deposit rising sharply above the far side of a small stream. This deposit is parti-colored, mainly blackish, but with some red, white, and bluish. The sides of the stream are bordered by treacherous, partly dry clay, hot and steaming in places. This extends upstream for several hundred feet, bordered by vegetation, mainly coarse grass and ferns. About a quarter of a mile further upstream the valley widens out into a broad flat area several hundred yards in width. On both sides of this the land rises rather abruptly, covered with vegetation, but with deposit underlying and outcropping here and there. There are several pools near the river and an attempt has been made to level and dike the land for rice, but the soil is clay with many twigs and decayed vegetation and the water bluish white with suspended clay. Most of the pools contain much material in suspension, either yellowish white or blackish. There is one clear and very hot pool of small size and other larger ones only moderately warm. Further out are desolate

flats with patches of pale yellowish efflorescent deposit, a few steaming fumaroles, but no pools nor vegetation. On the whole this area appears to represent the vestiges of former large and active thermal basins.

Tember Hot Springs

These springs and mud pots were described by Bickmore as lying two and one-half kilometers from Tompaso, and Wallace, giving them no name, reached them from Langoan. They lie between these two places and near the village of Tember which is about two and one-half kilometers east of Tompaso. From Tember the land spreads out in an extensive flat plain toward the south and east and the springs are scattered in this area, with numerous mud pots occupying the slope of the hill toward the north and east. On the north side of the road on this slope is an area of much crusty white deposit, very hot to the touch in places and with some treacherously soft spots. Springs are absent here, but there are several fumaroles, one forming a small steaming cone and there is much sulphur odor. Across the road back of a native kampong the slope has a number of pits and tunnels where the natives are mining the white deposit for whitewash; these openings emit considerable steam and fumes. Below the pits in a slight hollow are a number of very active mud pots with gray mud, surrounded by a crust which was colored brown, rust red, yellow, and white. These are probably much more active during the rainy season. Down a grassy slope to the south is one very hot pool with a hard sinter rim on which native women were pounding clothes that they were washing in the pool. Below this a shallow pool has been made by banking with sod and mud, used as a drinking place for water buffalo. From the vantage point of the mud pots one looks over the flat area where there are scattered groups of palms and some small woodlands but most of the area is diked for rice fields. Scattered among the trees and palms are a number of steaming pools which are diked where possible with ditches leading the water to other pools where it cools and can then be turned into the paddy fields. The hot springs are best reached by a lane which leads to the south from the road further down the hill. It is possible to reach the springs only by following the mud and sod ridges between the paddy fields and some are inaccessible because of the soft swampy surroundings. There are several steaming springs toward the mudpots on the slope but separated by palms and woodland. To the west are more paddy fields and steaming springs, scattered palms and woods and some grasses; in this area there were two or three large, almost dry, mud pots.

Sumatra

All of the thermal springs which we visited in Sumatra are located in the northern portion of the island as shown on the accompanying outline map (Fig. 2).

Sipirok Hot Springs

These are located within two or three kilometers of the town of Sipirok which is on a new direct road recently opened between Padangsidempoean and Taroetoeng. The distance from Padangsidempoean to Sipirok is 38 kilometers.

The springs form two groups. The largest is about two kilometers from the town by road and an additional walk of about one and one-half kilometers through rice fields and a lane to a small village where the springs are located. There are two large pools, about 30 feet in diameter, one with cemented walls in use for washing clothes and the other more or less in its original condition, although banked up to a higher level. The temperature of the water in the unwalled pool is 42° C. It is alkaline with a pH of 8.6 and specific gravity of 1.0036.

The springs of the second group are three kilometers by road from Sipirok. One large pool about 20 x 30 feet is connected with a bath-house and is used for washing. A second pool of nearly the same size contains much floating vegetation. In connection with these pools there is considerable overflowing water and seepage. The highest temperature of the water is 44.5° C., pH 8.6, and specific gravity 1.0026. A number of insects were obtained in the overflow from these springs as they meander down into the adjoining rice fields.

Panggaloan Hot Spring

This is on the road from Sipirok to Taroetoeng, 30 kilometers before the latter town. The water rises in a narrow pool next to the road (on the right) and flows for a distance of several hundred feet in a shallow ditch next to the road. The bottom is of blackish, soft, muddy soil and the edge soft and swampy. At the end of the ditch the water is led off under the road and finally to the river nearby. For a distance of several kilometers in the vicinity the road passes through hot springs deposits of clayey material, but no other actively flowing thermal water was observed.

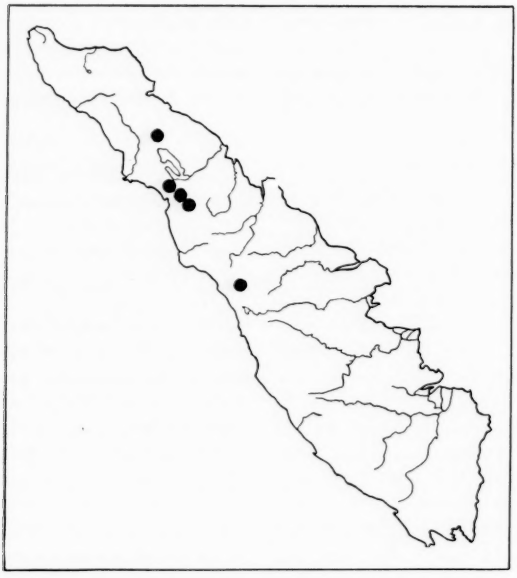

FIGURE 2. Sketch map of Sumatra, with the hot springs visited each indicated by a black dot.

TAROETOENG HOT SPRING

This is a very large spring just north of Taroetoeng near the outskirts of the town. It lies near the eastern side of the highway in an extensive area of several acres of white deposit. This deposit forms a rounded sloping mass some fifty feet in height with the surface contour broken at one place by a clear-cut group of terraces. Over these the water is flowing and the surface is stained with orange, green, and blackish due to algal growth. The crest of the deposit is steaming where the hot water emerges, and behind there rises a large wooded hillside underlain by tufa which is exposed here and there. At the foot of the slope the deposit is nearly level, including a couple of natural shallow pools, but below this the overflow has been impounded above the highway by a series of dikes which surround it and form an artificial pool several feet above the road which passes over tufa deposit at this point. This pool is nearly an acre in extent and filled with milky white warm water holding chalk in suspension, the latter probably due in great measure to the extensive use of the cooler part of the pool for bathing and swimming by the native population. At the southern end the overflow is led off at a temperature of about 40° as a good-sized stream that flows under the road to follow a course through dense vegetation to the westward into the nearby river.

The main area of deposit is bare of vegetation, but this creeps in rapidly from the sides, sometimes to become engulfed and thickly encrusted by dazzling white deposit. Most conspicuous among the encroaching vegetation are grasses, ferns, and isolated, apparently rapidly growing, naturalized agaves.

This spring is in general appearance similar to some of the sloping and terraced deposits about Yellowstone Park. The water has a pH of 8.4 which is almost exactly that of some of the water at Mammoth Hot Springs in Yellowstone Park where the same type of massive white deposit is laid down; the specific gravity of the water is 1.0074. Treatment of some of the material with hydrochloric acid dissolves it completely except for a very slight turbidity, showing it to be a practically pure calcium carbonate.

BRASTAGI SULPHUR LAKE

Eleven kilometers north of Brastagi on the road to Medan a path leads off on the right hand of the highway to the sulphur lake which may be reached by a walk of ten to fifteen minutes. The lake covers fully an acre, surrounded by jungle of a peculiar type which includes a large proportion

of stunted, more or less gnarled trees. This striking modification in the vegetation also extends less noticeably along a small stream that drains the lake, and would appear to be due to peculiarities in the soil or atmosphere in proximity to the sulphur lake. The edge is swampy near the outlet with sparse vegetation and about the shore here and there are remains of dead trees and shrubs coated at the base with white deposit. At the head of the lake the water is in constant, very gentle ebullition, although only warm, where it rises next to a rough shore of large, irregular, white rocks. The water is milky white, due to clay in suspension, with a faint sulphurous odor. It is noticeably acid (pH 6.5) with a specific gravity of 1.0046 and distinctly thermal with a temperature of 32°–34° C. The insect fauna includes water beetles, Hemiptera, and chironomid midges, both in the lake and the stream which drains it.

"Poison Springs"

The fumes arising from some of the Sumatran hot springs are reputed to be highly poisonous. One of these so-called poison springs is located in a government forest reserve not far north of Loeboeksikapang or some 85 kilometers north of Fort de Kock in middle Sumatra. This is visible in the dense jungle as a cloud of steam rising among the tall trees. At the edge of the highway nearby there are a few small seeps of water at which we saw numerous butterflies attempting to drink. A few dead or moribund specimens had evidently succumbed to some poisonous substance, probably an arsenical, in the water. The Dutch government has placed conspicuous signs in both Dutch and Malay warning visitors not to approach this spring too closely.

Java

Material was collected and observations made in several Javanese hot springs areas rather widely distributed over the island. The general location of these is indicated on the accompanying map. (Fig. 3).

Hot Wells of Batoe

These are in eastern Java, almost directly south of Sourabaja at a distance of about 100 kilometers by the highway, *via* Malang, and midway between the north and south coasts. They have been generally called "Hot Wells of Batoe" although they are actually at Songgoriti, a village just north of Batoe. The springs lie slightly off the highway and may be located by a hotel that has been built next to them, equipped with the usual bath houses. The permanence of the wells is indicated by very dilapidated Buddhist ruins immediately next to them. They are on an open slope at an altitude of 3,800 feet, behind which the mountains rise sharply at least 1,000 feet above. As the flow of water is slight the several wells have been inclosed in covered cement basins, the largest one in apparent ebullition, but with a temperature of only about 53° C. In the enclosed space above this well there is an odor of sulphur dioxide but the pH of nearby seeps is rather high (7.2). In shallow seeping pools next to a second, smaller well at temperatures of 35°–37° we obtained larvae of mosquitoes and stratiomyiid flies and one species of beetle.

From the mountainside above, the springs are seen to emerge at the foot of the steep slope where the land surface assumes a gentle slope southward towards Batoe.

Hot Wells of Krakal

These are on the southern side of the mountains not far from the south coast and practically at the middle of the island. They may be approached by a winding road from Keboemen beyond which they arise in the foothills at a distance of about eleven kilometers. The water in two enclosed concrete basins is 41° and 38° respectively and apparently devoid of animal life. In the neigh-

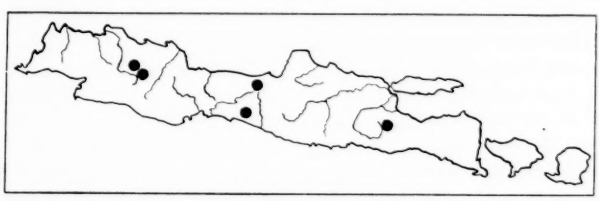

Figure 3. Sketch map of Java, with the hot springs visited each indicated by a black dot.

borhood there is practically no evidence of older hot spring deposits.

Dieng Hot Springs

These are adjacent to the Dieng Plateau at an elevation of about 7,500 feet, north of the town of Wonosobo. The region is near the middle of the island, nearer to the north than to the south coast. An automobile road, 24 kilometers in length has been recently completed which ascends the mountain from Wonosobo to the village of Dieng. The thermal waters are about two kilometers south-west of the village, south of the swampy plateau proper. One large spring is particularly interesting as it was described nearly 100 years ago and is still in practically the same condition. This is a boiling pool some twenty feet in diameter in the center of which are several irregular jets of water that spout alternately to the height of several feet (cf. Peale, '83, p. 350). The early account speaks of the water rising to a height of 3–4 feet. This is evidently an old spring, once much larger, as it lies at the foot of a sloping mass of deposit about an acre in extent. The overflow of this pool is thick with dark gray mud covered with a thin superficial layer of water, but contained some insect life. It is quite acid, with a pH of 6.3. There are also numerous fumaroles, a small stream of very hot water and several small ponds of sulphurous, but not warm water in the neighborhood.

Kamodjan Hot Springs

These are in western Java northwest of Garoet, reached by a toll road that climbs Mount Goentoer for a distance of 22 kilometers from Trogon, a village just north of Garoet. The thermal activity extends over an area of some ten acres in a shallow basin or flat valley about a quarter of a mile in diameter. Beyond, the land rises much more abruptly to the top of the mountain. There are numerous fumaroles and steaming pits, the latter of small size but emitting much steam which rises in clouds among the tree ferns and other plants of the tropical jungle. Scattered about are also a considerable number of mud-pots, many of them small, but several attaining a diameter of twelve feet or more, filled with thick grey or buff mud. The area lies within a forest reserve and is in its natural state except for one steam vent which has been closed and fitted with a large iron pipe. Here a native performs stunts for the few tourists who venture so far from the beaten path, exploding paper bags, blowing a large bamboo whistle and creating much noise to mar an otherwise most impressive and spectacular series of natural phenomena.

This is the crater of Mount Goentoer, at an elevation of 7,400 feet. Just below are several large pools filled with warm, very murky water, their marshy edges lined with greyish clayey mud. Beyond is a bank of luxuriant herbs and ferns that merge into the adjacent jungle. These pools represent the overflow from the activity on the slope above and undoubtedly receive much more water during the wetter months.

Tjipanas Hot Springs

These are not far from Kamodjan, reached by a short side-road from Trogon. They are much lower, at an altitude of about 2,500 feet near the foot of the north slope of the mountain, and the thermal activity is confined to flowing hot water. One large spring, in connection with which a hotel and bath house have been built, is confined in a large concrete tank at a temperature of about 60° C. In a flat area below this, occupied by the native village, are a number of fish-breeding ponds supplied by thermal water at a temperature of about 40° C. where it enters the ponds. Some frogs and tadpoles were obtained here, but no fish were observed in the thermal part of the ponds.

Systematic Account of the Fauna

Insects

Collembola

So far as I am aware, no spring-tails have hitherto been reported as associated with hot springs in other parts of the world, but Handschin ('32) mentions three species collected by the Thienemann expedition close to hot springs in Java, although no temperature records are given. These species are *Hypogastrura armata* Nic., *Isotoma sensibilis* Tullb. and *Trichogaster bispinosus* Handsch., all from the borders of hot springs at Kandang Badak in Western Java.

Odonata

Libellulidae

Five species of nymphs of this family are represented in the collections from Sumatra and the northern Celebes. All are members of the subfamily Libellulinae. As there are over twenty genera of this group in the region, it has been impossible to do more than designate the several forms by numbers. In each case I have included with the data a brief description and a figure of

FIGURE 4. Labia of Odonata. *a*, libellulid nymph No. 1; *b*, libellulid nymph No. 2; *c*, libellulid nymph No. 3; *d*, libellulid nymph No. 4; *e*, libellulid nymph No. 5.

the labium (Fig. 4) which should make possible their recognition.

Compared with the extent of the known fauna of these islands it is evident that quite a considerable part extends into thermal water.

(**Libellulinae**) No. 1. (Fig. 4, *A*)

Very dark brown in color. Median lobe of mentum wider than long; its anterior margin weakly crenulate, not distinctly produced at the middle as a lobe. Mental setae three on each side, long, evenly spaced; between these groups with an oblique band of minute setae on each side, numbering about 12. Labial palpi with four lateral setae of nearly equal length, the margin incised at the insertion of each seta; apical margin with five or six rounded, scarcely evident teeth, indicated only by the incisions that separate them; one spine inserted at each incision. Head generally densely hairy, especially between the antennae. Legs stout; first and second joints of hind tarsi subequal, third slightly longer. Four dorsal hooks, on segments 4, 5, 6, 7, but none on the eighth. Eighth and ninth abdominal segments obsoletely toothed at the hind angle; lateral terminal appendages clearly half as long as the superior one which is very weakly concave along its lateral edges.

Three nymphs, one evidently practically full-grown, were taken in the Paso Hot Spring, North Celebes in water at 36° C.

(**Libellulinae**) No. 2. (Fig. 4, *B*)

Body stout; densely hairy, including the legs. Color pale brown, the head above much darker due to oblique dark brown stains on each side of the front. Labium with the median lobe somewhat wider than long, the margin with very fine crenulations, each notch bearing a single minute spine, the median projection quite pronounced. Labial palpi each with six or seven setae of large size, the apical margin strongly notched, each incision bearing one short and one extremely minute spine. Mental setae three on each side; medially to these with a decreasing series of eight or nine small ones and a patch of a few very minute ones at the middle. Abdomen with a median hook on segments 4, 5, 6, 7, 8, these becoming larger on the posterior segments; tergites eight and nine each bearing a short black-tipped

spine at the posterior lateral angle. Lateral terminal appendage about half as long as the dorsal ones. First joint of hind tarsi two-thirds as long as the second.

One apparently full-grown nymph and numerous smaller ones; varying greatly in size, from the Sipirok Hot Springs, Sumatra, water temperature 37°. They were present in both groups of springs at this place.

(**Libellulinae**) No. 3. (Fig. 4, *C*)

Color pale brownish yellow, darker on the abdomen beyond base; body very densely hairy, especially on the thorax and legs. Labium with the median lobe slightly wider than long, with a very small, but distinct median projection in front; the anterior margin very finely crenulate, each incision bearing a very short spine; three mental setae on each side, these quite slender; between these groups is a series of setae placed in an oblique line on each side, a few of these bunched together near the median line. Labial palpi with a series of about eight setae along the outer edge, the anterior ones and the posterior one shorter than the others; apical edge not distinctly indented, but with six or seven short single spines; apical spine stout, but short. Hind legs with the first joint of tarsi much shorter than the second above, the third longest. Eighth and ninth abdominal segments each bearing a short spine at the posterior lateral angle. Lateral terminal appendage one-half as long as the superior one which is slightly concave along the sides.

Three nymphs of this form were obtained in the Lake Linau Hot Spring in water at 38°, pH 3.5. Two of these are large, one apparently practically full-grown.

(**Libellulinae**) No. 4. (Fig. 4, *D*)

Possibly the same as No. 3, but with the median lobe of the mentum much more prominent and with the anterior margin of the mentum sloping more strongly on the sides; apical edge of labial palpi deeply crenulate. Lateral terminal appendage of abdomen very short, not quite one-third as long as the dorsal one. Head with a conspicuous dark brown marking on the front between the eyes.

There are five nymphs from the Tember Hot Springs, Northern Celebes in water at 37°, pH 7.4; also one from the nearby springs at Paso, in water at 37°, pH 7.3.

(**Libellulinae**) No. 5. (Fig. 4, *E*)

Rather slender, the body almost bare except for short stout bristly hairs on the head behind the eyes and very long slender ones on the tibiae and the apex of the abdomen. Color quite pale; head finely, irregularly mottled with brown; abdomen brownish above with minute darker spots and paler markings, the latter especially toward apex. Head very short behind the eyes, the temples strongly oblique. Ninth abdominal segment with a very minute tooth at the apical angle. Mentum and labial palpi strongly bristled. Median lobe of labium angularly produced, the sides slightly concave in outline and very indistinctly toothed or crenulate. Labial palpi with ten bristles along the outer edge the apical ones long and stout, the two basal ones conspicuously shorter. Mental setae about eleven on each side, strong; the five lateral ones long, the next two shorter and the remainder decreasing in size to the median line; none, however, are really of minute size. Inner and apical margins of labial palpi very nearly smooth, the apical bristles very strong. Legs very slender; first joint of hind tarsi less than half as long as the second which is distinctly shorter than the third.

One nymph from the Langoan Hot Spring, Northern Celebes, and a second one, exactly similar, but only partly grown from the Tember Hot Springs, Northern Celebes.

Coenagriidae

There is a single small nymph from the Paso Hot Springs which is perhaps a species of *Ischnura*. Zygopteran nymphs appear to be much rarer in the East Indian Hot springs than in those of America where they usually outnumber those of the Anisoptera.

Hemiptera

We obtained six species of the order Hemiptera in hot springs to which may be added five others previously reported from thermal waters in the same region. These belong to nine families, Nepidae, Belostomatidae, Naucoridae, Corixidae, Helotrephidae, Pleidae, Hebridae, Veliidae, and Gerridae. This series is more extensive than that recorded from North American springs, but does not include the Notonectidae which are frequent inhabitants of American hot springs. As has been found previously, none of the aquatic Hemiptera ever seem to invade water of more than very moderate temperatures, usually not extending above 36°–38° C.

I am indebted to Professor H. B. Hungerford for the identification of our material which he very kindly examined.

NEPIDAE

Laccotrephes sp. (nymphs)

There are several nymphs in different stages among the material we collected in the Sipirok Hot Springs in northern Sumatra at a temperature of 39°, pH 8.6. This seems to be the first record of a member of this family in thermal waters.

BELOSTOMATIDAE

Sphaerodema sp. (nymph)

(probably *S. rusticum* Fabr.)

The nymph which was taken in the Sulphur Lake at Brastagi, is probably this common Malayan species which has been reported from many localities in Sumatra.

NAUCORIDAE

A single naucorid nymph from Sipirok in water at 37° represents the material in this family. In America we have commonly collected species of *Ambrysus* in thermal waters.

CORIXIDAE

Micronecta sp.

Nymphs and females only of a species of *Micronecta* were taken by us in the overflow from the Panggaloan Hot Spring, northern Sumatra, in water at 37°.

Micronecta quadristrigata Breddin

Lundblad ('33) has reported the occurrence of this species in numerous places in Java and Sumatra on the basis of collections obtained by the Thienemann expedition. Among these is included the Kadjai Hot Springs in Central Sumatra near Lake Singkarak, in a swamp at 39°. A second thermal locality is the Bukit Kili Hot Springs in the same general region, in water at 38°. This is a common Indomalayan corixid.

HELOTREPHIDAE

The peculiar genus *Idiotrephes* of this small family recently described by Lundblad ('33) was collected among other localities in Sumatra in the overflow from a hot spring (Subang Ajam) near Tjurup in southern Sumatra, only in water of moderate temperature (32°–34°). Other series came from non-thermal water.

PLEIDAE

Plea liturata Fieber

Lundblad ('33) records this common Malayan species from the overflow of the Bukit Kili Hot Springs near Lake Singkarak in central Sumatra. The temperature of the water is not stated.

Anisops cleopatra Distant

This species has been reported by Lundblad ('33) from the same Bukit Kili Hot Springs in water at 38° C. Another species of the same genus, *Anisops thienemanni* Lundblad was collected by Thienemann in sulphurous water at several places on the Dieng Plateau in Central Java.

HEBRIDAE

Hebrus nipponicus Horvath

This species has been recorded by Lundblad ('33) from the hot springs at Koeripan in western Java and also from the Samosir peninsula of Lake Toba in northern Sumatra, in the latter place associated with solfataras.

VELIIDAE

Three species of this family are known to be associated with thermal springs in the Dutch East Indies.

Microvelia albolineata Torre Bueno

This species was abundant about the borders of the Sulphur Lake at Brastagi in northern Sumatra and also in the stream that drains the Lake. It was originally described from Sumatra (Torre Bueno '27) and is known also from Bali. Another related form, *Microvelia plumbea* Lundblad was described from several localities on the Dieng Plateau in central Java all of which are associated with solfataras and sulphurous waters. The water of the Brastagi lake is acid with a pH of 6.5 and temperature of 32°–34° C.

Rhagovelia femorata Dover, var. **sumatrensis** Lundblad

This variety of an Indomalayan species was described from several localities in Sumatra by Lundblad ('33). One of these, the lime springs of Panjingahan near Lake Singkarak in central Sumatra represent thermal waters.

GERRIDAE

Limnogonus fossarum Fabr.

We collected this species in thermal water at two localities in the northern Celebes; the Lan-

goan Hot Spring, northern Celebes and at the Paso Hot Springs. The water in these springs is 35°, pH 7.7 and 37°, pH 7.3, respectively.

The species has been previously found in thermal waters in Sumatra (Lundblad, '33), in the hot spring Subang Ajam near Tjirup, southern Sumatra and on the Samosir peninsula in Lake Toba, central Sumatra in the vicinity of solfataras. It is a widespread and abundant water-strider throughout the Indomalayan region. Another gerrid, *Ptilomera pamphagus* Breddin is recorded by Lundblad from the Subang Ajam hot spring, but without further data.

Diptera

As usual this order is well represented by members of several families.

Chironomidae

Tanypus (Protenthes) punctipennis Meigen

This species, common to Europe and North America, was recorded by Johannsen ('31, p. 505) from both Java and Sumatra in the Dutch East Indies. Zavrel ('33) has studied the larvae from which some of the adults were reared and included among these is one from Kadjai, Sumatra in a warm swamp at a temperature of 39°. Our larvae are from a hot spring near Sipirok, Sumatra.

The species also develops regularly in non-thermal water, in the East Indies as well as in the other parts of its range.

The labium and glossa of a larva from Sipirok is shown in fig. 5, *g*, *h*. The median pale lobe of the mentum is narrowly incised laterally where it joins the first pigmented lateral tooth while the more lateral teeth are more deeply separated. The five teeth of the glossa are of nearly equal length, but a line joining their tips is distinctly convex. The head is barely longer than wide, about one-third longer than the antenna which bears the sense-pit just beyond the apical third of the first joint.

Metriocnemus ? sp.

A single larva from the Sipirok Hot Spring in water at 37°, pH 8.6, probably represents a

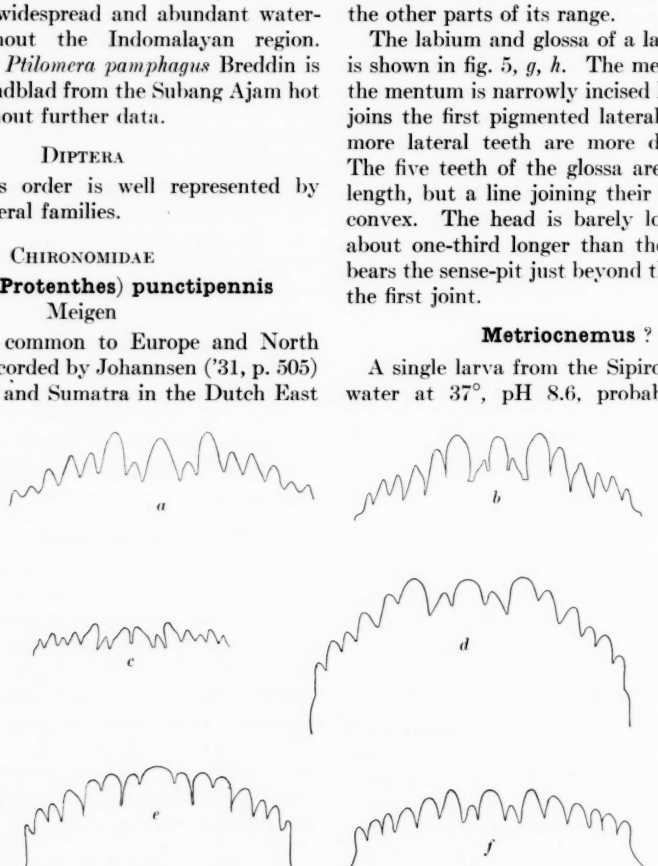

Figure 5. Outline of mentum of several chironomid larvae. *a*, chironomine No. 1; *b*, chironomine No. 2; *c*, chironomine No. 3; *d*, chironomine No. 4; *e*, chironomine No. 5; *f*, chironomine No. 6; *g*, *Tanypus* (*Protenthes*) *punctipennis*; *h*, glossa of same.

species of this genus. Thienemann ('32) mentions the occurrence of an unidentified orthocladiine larva which he collected in a hot spring on the Samosir peninsula in Lake Toba in Sumatra. This was living in water at 42° in the overflow of a spring in a solfatara region.

Aside from these two species there are six others from various hot springs which it has not been possible to identify with any degree of precision beyond the fact that all are referable to the Chironominae.

These are listed below, together with the localities and temperature of the water in which they were living. It is evident that members of this group commonly find a congenial environment in hot springs here as in other parts of the world, although none of our records involve water of any high temperature.

Chironominae from East Indian Hot Springs

No.	Locality	Temp. of water
1	Sipirok Hot Springs, Sumatra	37°
2	Panggaloan Hot Springs, Sumatra	
3	Panggaloan Hot Springs, Sumatra	
4	24 kilom. N. of Kotanopan, Sumatra	35°
	Brastagi Sulphur Lake, Sumatra	34°
5	Lake Linau Hot Springs, Celebes	38°
6	Kamodjan Hot Springs, Java	38°

No. 1 has three pairs of long ventral gills; the first lateral teeth of the labium deeply set off from the median one (Fig. 5, *a*) and the sensory pore of the antennae at the basal fourth of the first segment; head broad.

No. 2 has two pairs of ventral gills; the first lateral teeth of the labium scarcely set off from the median one (Fig. 5, *b*); the sensory pore of the antenna at the basal fourth of the first segment; head broad.

No. 3 lacks ventral gills; the median tooth of the labium is divided by a median notch (Fig. 5, *c*); the sensory pore of the antenna is small, placed at the apical third of the first joint.

No. 4 has the median tooth of the labium shorter than the second lateral one (Fig. 5, *d*); two pairs of ventral gills; a large sensory pore at the middle of basal third of the first antennal joint.

No. 5 is similar to the preceding, but the median tooth of the labium is broader and the first lateral one long (Fig. 5, *e*).

No. 6 has the median tooth well separated from the first lateral ones which are very short (Fig. 5, *f*); first joint of antenna with the large sensory pore just before the middle.

Chironomus (Cladotendipes) inferior Joh.

This species was reared from larvae collected at Wai Panas, Lake Ranau, southern Sumatra in water at a temperature of 40°. The larva is partially described and figured by Lenz ('37). This form is not represented in our collections.

Pentapedilum convexum Joh.

Larvae of this species were taken in a highly acid spring (pH 4-) near sulfataras at Sigaol, Samosir, Sumatra. It has been found also in a non-thermal swamp with *Sphagnum* (Lenz '37).

Some other records of Javan and Sumatran species of *Chironomus* and related genera from thermal springs are given by Lenz ('37). These include several relating to unidentified larvae from sulphurous water on the Dieng Plateau, Java and one from a highly acid spring (pH 2.7) at Sigarol, Toba Lake, Sumatra at 35.5° C., and also *Chironomus costatus*, var. *apicatus* Johannsen from highly sulphurous water on the Samosir peninsula in Lake Toba, Sumatra at 29° and pH 2.83.

CERATOPOGONIDAE

No larvae belonging to this group were obtained by us in East Indian Hot Springs. Three species have, however, been found breeding in thermal water on these islands.

Bezzia assimilis Johannsen

Arch. f. Hydrobiol., suppl. vol. 9, p. 445 (1931).
Mayer, ibid., suppl. vol. 13, p. 193 (1934) (*Probezzia*).

The type specimen was reared from a larva living in swamp water at 39° C. in the Kadjai Hot Springs near Singkarak, Sumatra. A varietal form of the species has been taken in non-thermal water at Buitenzorg, Java.

Stilobezzia notata de Meijere, var. **perspicua** Johannsen

Arch. f. Hydrobiol., suppl. vol. 9, p. 432 (1931).
Mayer, ibid., suppl. vol. 13, pp. 187, 194 (1934).

The types were reared from larvae collected at the same locality as the foregoing species, also at 39° C. Other specimens came from larvae breeding in a rice field at Lake Ranau, Sumatra.

Dasyhelea tersa Johannsen

Arch. f. Hydrobiol., suppl. vol. 9, p. 421 (1931) (*Tetraphora*).
Mayer, ibid., suppl. vol. 13, p. 180 (1934).

The larvae of this remarkable species were found living in water at 51° C. in the overflow of a hot spring near Tjibodas, Java. This is a large spring at an altitude of 2,150 meters (6,550 ft.) on Mt. Gedeh. Here the larvae were found to be living in masses in the algae that cover the rocks over which the hot water flows rapidly. This is a most remarkable record, and as might be expected the *Dasyhelea* larvae were the only animal life in the overflow.

It is well known that members of this family and the Chironomidae sometimes inhabit very hot water. The present writer once collected larvae of a species of *Chironomus* in water at 49° in a thermal pond (Brues '24) in Yellowstone Park, U. S. A., but I know of no record of so high a temperature as the 51° just cited, except one by Wood (cf. Brues, '28, p. 385) of an unidentified midge larva which he found in Owens Valley, California also at 51° C. (124° Fahr.).

Culicidae

The larvae of certain mosquitoes occur to some extent, although not abundantly in thermal waters. We obtained two species in the present collections. Larvae of a species of *Anopheles*, probably of *A. rossi* Giles or *A. ludlowi* Theobald were quite numerous at the Sipirok Hot Springs, Sumatra. Here they were living in alkaline water (pH 8.6) at a temperature of 38°. A second lot were in seeps about the Hot Wells of Batoe in water at a temperature of 35°–37°, pH 7.2.

Brug ('31) records *Anopheles rossi*, among other localities, from the warm surface water of Lake Lamongan, Java, which reaches a temperature of between 30° and 34° in the middle of the day. Lake Lamongan is a beautiful deep crater lake near Klakah, Java, where the daily and monthly temperature fluctuations in water temperature have been carefully studied by Ruttner ('31). The lake is some 780 feet above sea level, well supplied with floating vegetation. The surface temperature may rise to 33.8 and drop to 27.8 so that it frequently reaches 33°. At a slight depth of ten inches it is more constant, but may reach 30° or slightly higher. However in floating masses of aquatic plants the temperature may rise much higher, in growths of *Hydrilla* to 39.7°, and in another aquatic plant, *Eichhornia*, which produces also air-leaves that shade the surface the water temperature may reach 36.9°. Records of *Anopheles* from thermal springs in America show also that their larvae invade water of moderately high temperatures much more commonly than do those of other mosquitoes.

Brug also records *A. rossi* or *A. ludlowi* from a hot spring in a swamp at 39° near Lake Singkarak in central Sumatra and *A. aconitus* Dönitz from Lake Lamongan, among *Hydrilla* plants, but in the shade. In the latter case no temperature is noted, but the water was probably well above 30°.

A single mosquito larvae from Sipirok in water at 38°, pH 8.6 belongs to the genus *Culex*, but is not in sufficiently perfect condition to permit a more accurate determination. Brug ('31) records *Culex malayi* Leic. from Lake Lamongan, in *Hydrilla*, but gives no water temperature.

Simuliidae

The only black-fly larvae collected were obtained in sulphur water 24 kilometers north of Kotonopan where a small warm stream passes beneath the road through a culvert.

The occurrence of members of this family in thermal waters is not general and has been recorded in only two or three instances (Brues, 1932, p. 243).

The Sumatran larvae belong to a European species, *Simulium latipes* Meigen, of which Edwards ('34) has described two East Indian varieties from Java.

Stratiomyiidae

As these larvae are characteristic inhabitants of thermal waters in temperate regions it was not surprising to find them present in similar situations in the East Indies. They were found, however, only at two places, one in Sumatra and the other in Java.

A series of larvae which quite surely belong to the genus *Odontomyia* were collected in warm seeps at the Hot Wells at Batoe in Java. This water was at a temperature of 35°–37° and pH 7.2. They were extremely abundant and among them were a few that had already pupated. The body is of the usual form, with a broad dark median band containing irregular pale dots; the sides are pale, marked with black dots that form on the side of each segment two more or less clearly longitudinal series. Terminal segment in the extruded position about two and one half times as long as broad with the anal slit near the middle; apical margin seen from above, rounded and slightly sinuate between the middle and sides. Penultimate segment and the three or four segments that precede it each with a pair of hooks on the ventral margin toward the middle. Occa-

sionally these hooks are doubled so that there are four to a segment; but this doubling seems never to appear on the penultimate or antepenultimate segment. Length from 15 to 20 mm.

It might seem that the doubling of the hooks on certain segments indicates that two species are concerned, but the larvae seem otherwise identical and the doubling is sometimes incomplete, *i. e.*, three hooks on one segment.

A single larva belonging to the family Stratiomyiidae was collected on the edge of the Sulphur Lake at Brastagi, Sumatra, in water at 34°, pH 6.5. This is elongate, of the form of *Odontomyia* or *Stratiomyia*, but evidently represents either some other genus of which the larvae are hitherto unknown, or possibly a form related to *Euparyphus*.

The antennae are inserted at the sides of the head, perhaps a little, but not much higher than in *Odontomyia*. Apical segment nearly twice as long as wide, the anal opening broad, nearly as wide as long; spiracular opening not visible from below, partly so from above as a broad transverse slit, fringed with long pectinate or plumose hairs that are slightly longer than the width of the segment. Dorsally the penultimate and four preceding segments bear a series of very small, stout, thorn-like spines near the posterior margin; these are more minute and numerous (about 12) on the anterior two of these segments. Beneath, the penultimate segment bears a pair of rather small hooks, repeated on the three preceding segments, but becoming successively smaller, the most anterior pair minute. Color dark, mottled with irregular wavy longitudinal streaks. Length 8 mm., greatest width 1.6 mm.

Ephydridae

One species has been recorded from a hot spring in central Sumatra by Cresson ('32). This is *Notiphila phaca* Hendel found by Thienemann in a hot spring swamp at 39°, adjacent to the Kadjai Springs, near Lake Singkarak. The larvae insert the posterior spiracular tube into roots of the plant, *Bacopa*. This is the third genus of the family to be found developing in thermal water. *Ephydra* is commonly found in such locations in the United States, usually, but not always, in water containing considerable amounts of sodium chloride. *Scatella* is represented by several species in hot springs. Recently Tuxen ('36a) has found a variety of the European *S. stagnalis* Fall. very commonly present in the thermal springs of Iceland. This form was originally described by Collin as a distinct species, *S. thermarum*. Also in North America, Japan, Italy, Greenland, probably in New Zealand, and finally in Kamtschatka, other species inhabit hot springs. In the latter country Malaise (*teste* Tuxen '36a) collected the larvae of *S. costalis* Hendel in water said to be at 55° C. As this temperature is decidedly higher than previous authentic records for other animal life, I believe that it should be accepted with great caution until further corroborative observations are made on the Kamtschatkan form. However, according to Tuxen ('36b) not only does *Scatella* extend into water of 55° in Iceland, but he reports finding larvae and pupae in water at 65° C.! These were presumably alive although this is not directly stated in the text of his paper. On this basis, Tuxen has been led to believe that the physiological requirements of animal life in Iceland are radically different from those in other parts of the world. This is, of course, a conclusion that will not be accepted by biologists at large without abundant proof.

Other Invertebrata

There are contained in the reports of Thienemann's expedition to the Dutch East Indies a number of records by various workers relating to several groups of invertebrates that have not been mentioned in the previous pages of the present paper. As these are scattered through various papers in the Archiv für Hydrobiologie over a number of years, I have excerpted these and included them here for the sake of completeness. Specific citations to these papers are given in each case.

Protozoa

In his account of the shell-bearing Rhizopoda Harnisch ('32) lists twelve species from thermal waters in Java and Sumatra as follows:

Nebela tubulosa
Kali Tjibodas, Java, 45° C.
Nebela lageniformis
Tjibodas, Java, 45° C.
Nebela tenella (?)
Tjibodas, Java.
Quadrula discoides
Tjibodas, Java, 45° C.; overflow from hot springs at Lake Ranau, Sumatra, 58° C.[1]

[1] It must be noted that it is not possible to determine whether minute organisms are alive in mass collections without an immediate resort to microscopical examination in the field. This is particularly true of the present

Heleopera picta
Warm Spring, Musi River, Sumatra, 32°–34° C.
Arcella vulgaris
"Hot Spring."
Arcella artocera (?)
Tjibodas, Java.
Phryganella hemisphaerica
42.7° C., no definite locality.
Cyphoderia margaritacea
Thermal water overflow, no locality.
Euglypha strigosa
Condensation zone, Tjibodas Hot Springs, Java.
Corythion pulchellum
Same locality.

NEMATODA

Since the publication of the summary in my previous account (Brues '32) several helminthologists have contributed extensively to the knowledge of the nematodes that inhabit thermal waters.

Hoeppli and Chu ('32) have investigated the free-living nematode fauna of several hot springs in China and Formosa. Their collections contained material of nine species, five of which are described as new. As may be seen from the following list all were obtained in water considerably above 30°, and in several instances in a spring where the temperature reached 48.5°.

Greenia orientalis Hoeppli & Chu
Tangshan, near Nanking, China, 35°.
Wen Chu'an, near Peiping, China, 34°.
Foochow, China, 35°.
Changchow, China, 39°; 48.5°.
Plectus chengmohliangi Hoeppli & Chu
Foochow, China, 34.5°.
Microlaimoides lingi Hoeppli & Chu
Foochow, China, 34.5°.
Cyatholaimus chungsani Hoeppli & Chu
Changchow, China, 39°; 48.5°.
Monhystrella ginlingensis Hoeppli & Chu
Tangshan, near Nanking, China, 35°.
Monhystera filiformis, var. *fukienensis* Hoeppli & Chu
Changchow, China, 48.5°.
Diploscapter coronata (Cobb)
Changchow, China, 39°.
Aphelenchus parientinus Bastian
Changchow, China, 39°.
Foochow, China.
Trilobus allophysis (Steiner)
Wen Chu'an, near Peiping, China, 34°.

group as identifications are based in great part on the structure of the shell.

Two of these were later found by Schneider in East Indian thermal waters and one is common also to hot springs in Africa. While they found a number of instances where types characteristic of brackish water occurred in their collections, these were mainly ones of quite ubiquitous occurrence in varied kinds of environments. They noted also a very wide distribution in the case of thermal species, although this is of course a common occurrence among a great many of the free-living nematodes.

Recently a few nematodes from hot springs in equatorial Africa have been dealt with by De Conninck ('37). These were from Mount Banze (Lake Kivu) and include eight species, as follows: *Dorylaimus filiformis, D. juvenilis, D. paraobtusicaudatus, Plectus sambesii, Rhabdolaimus terrestris, Achromodora ruricola* and *Cephalobus persegnis*. The *Plectus* is known also (as *P. paracommunis*) from Yellowstone Park. Unfortunately no accurate temperature determinations are available as the water in which the collections were made varies between 30° and 50°.

Finally, Schneider ('37) has just published the results of his study of the East Indian free-living nematodes collected by the Thienemann expedition to Java and Sumatra. This series includes eighteen species found in the water of truly thermal springs. In the following list only actual thermal records are included although practically all of the species are recorded from non-thermal stations.

Trilobus malayanus Schneider
Wai Panas, Lake Ranau, Sumatra, 40°.
Bukit Kili Hot Springs, Sumatra, 38°.
Kadjai Hot Springs, Sumatra, 37°.
Lake Toba, Sumatra, 32°.
Prismatolaimus intermedius (Bütschli)
Tjiliwong, Tjibodas, Java, 33°.
Mononchus macrostoma Bastian
Lake Ranau (Lyngbya zone), Sumatra, 40°.
Dorylaimus flavomaculatus Linst.
Wai Panas Hot Springs, Sumatra, 41°.
Also several localities in warm surface water, 29°–33°.
Dorylaimus filiformis Bastian
Lake Ranau (Lyngbya zone), Sumatra, 40°.
Hot Spring, Musi River, Sumatra, 42.7°.
Hot Spring, Musi River, Sumatra, 46°.
Kadjai Hot Spring, Sumatra, 39°.
Dorylaimus granuliferus Cobb
Bukit Kili Ketjil Hot Spring, Sumatra, 51°.

Plectus sambesii Micol.
Bukit Kili Hot Spring, Sumatra, 38°.
Rhabdolaimus terrestris De Man
Bukit Kili Hot Spring, Sumatra, 38°.
Hot Springs, Kandang Badak, Java, 45°.
Monochromadora monhysteroides Schneider
Wai Panas, Lake Ranau, Sumatra, 40°.
Monochromadora monhysteroides var. *longicaudata* Schneider
Bukit Kili Hot Springs, Sumatra, 38°–41°.
Kadjai Hot Springs, Sumatra, 37°.
Monochromadora crassicauda Schneider
Hot Spring, Musi River, Sumatra, 42.7°.
Achromadora ruricola De Man
Bukit Kili Hot Spring, Lake Singkarak, Sumatra, 38°.
Ethmolaimus pratensis De Man
Lime Hot Springs, Kuripan, Java, 34.3°.
Monhystera filiformis Bastian
Bukit Kili Ketjil, Lake Singkarak, Sumatra, 51°.
Hot Spring, Mt. Kapuran, Laki, Java, 37.4°.
Monhystera vulgaris De Man
Bukit Kili Ketjil, Lake Singkarak, Sumatra, 51°.
Hot Spring, Mt. Kapuran, Laki, Java, 37.4°.
Diplolaimella allgeni Schneider
Hot Spring, Mt. Kapuran, Java, 37.4°.
Cephalobus tenuis Schneider
Kadjai Hot Spring, Sumatra, 37°.
Hot Spring, Mt. Kapuran, Java, 37.4°.
Aphelenchus parietinus Bastian
Solfatara, Samosir Peninsula, Lake Toba, Sumatra, 36.5°.

As only 79 forms were obtained by the expedition it is surprising to find that 18, or nearly 25% of the whole series occur in hot springs. If those found in the warm surface water of lakes or at temperatures above 30° along their shores had been included, the list would have been appreciably augmented.

A number of the species are widespread forms and five are common to the African springs mentioned above. None are definitely restricted to hot springs, although several appear to be most commonly represented in this environment, e. g., *Plectus sambesii*, *Dorylaimus filiformis;* and both are known from hot springs in other parts of the world. Species of two typically marine genera were found in thermal waters of high chloride concentration. It is noticeable, of course, that the waters of the East Indian springs generally contain only relatively small quantities of salts in solution.

Annelida

One species of leech, *Limnatis* (*Hirudinaria*) *manillensis* Less. a widely distributed Indomalayan form has been taken once in thermal water (Augener '31). The record is from the Bukit Kili Hot Springs, Singkarak, Sumatra, in water at 38°.

A small oligochaete of the family Enchytraeidae, probably a species of *Enchytraeus*, is reported by Michaelsen and Boldt ('32) from a hot spring at Tjibodas, Java taken in water at 41° C. This is an interesting record, apparently the first for this group in thermal waters.

Arachnida (Acarina)

Two species of mites have recently been recorded from thermal springs in the Dutch East Indies by Vitzthum ('31) and Willmann ('31), based upon collections made by the Thienemann limnological expedition.

The most interesting one is a gamasoid mite, *Platyseius mollicomus* Berlese, belonging to the family Laelaptidae. This represents, according to Vitzthum the first instance among the terrestrial Acarina. The species is at least semiaquatic, having been found in masses of algae at a temperature of 41° in a hot spring at Tjibodas, Java.

However, among the oribatoid mites that were contained in the same collections from hot springs which has been discussed by Willmann, *Malaconothrus pseudolamellatus* Willmann was found in moss near a hot spring at Tjibodas, Java, at 35°. Individuals in various stages of development were present, showing that this is a normal habitat.

Crustacea

Among the Crustacea, a number of amphipods, ostracods, and isopods are known to form a component of the hot springs fauna. Certain amphipods are often abundant, but so far none have been reported from any East Indian springs.

Copepod crustaceans do not commonly occur in thermal waters, but there have accumulated during recent years a few records. Carter and Beadle ('30) found in the swamps of the Paraguayan Chaco certain copepods, not identified, living in water that is periodically subject to rises in temperature to between 40° and 42° C. In hot springs in the Dutch East Indies, Kiefer

('33) and Heberer and Keifer ('32) have recorded five species at maximum temperatures ranging from 35° C. to 39° C. These are *Halicyclops thermophilus*, from the salt springs at Koeripan, Java at 35° (not 45° as previously stated by Menzel); *Paracyclops fimbriatus; Paracyclops eucyclopoides*, *Microcyclops varicans*, 39°; *Mesocyclops leuckarti*, 39°. Of these, *Halicyclops* has been found so far only at the place mentioned, at temperatures not below 37° and *Paracyclops eucyclopoides* although not an obligatory thermophile thrives better at the higher temperatures.

In his account of the Copepoda Harpacticoida obtained by the Thienemann expedition, Chappuis ('31) mentions three species from a warm spring in northern Sumatra, at Ayer Panas near Tjurup. These are *Elaphoidella bidens coronata*, *Schizopera tobae* and *Parastenocaris longicaudis*, from water at 29.5° which is really hardly to be considered as thermal, except for its origin.

Apparently only a single species of Ostracoda has been found in hot springs in the Dutch East Indies, although members of this order are quite well represented in North American thermal waters. This is *Stenocypris humilis* described by Klie ('32) from Sumatra. Specimens were taken in water at 39° in a hot spring marsh at Kadjai, near Lake Singkarak in central Sumatra.

Among the Cladocera two East Indian species are known from thermal springs (Brehm '33). These are *Bosmina longirostris* from Kali Djermih at Tjurup, Sumatra in water at 34°, and *Scapholeberis kingi* in a solfatara spring at Sigaol on the Samosir Peninsula, Lake Toba, Sumatra in water at 35.5° having the extremely acid reaction of pH 2.68.

Mollusca

Members of three families of gastropods are included in the material that we collected in East Indian hot springs. They represent apparently the first records from this region.

Lymnaeidae

Lymnaea rubiginosa Michelin was taken by us in hot springs both in Sumatra and Celebes. In the Paso Hot Springs in the northern Celebes this species was common, at the moderate temperature of 36° in water of pH 7.3 and also in the Sipirok Hot Springs in Northern Sumatra in water at 37°, pH 8.6. Other species of *Lymnaea* are known to inhabit thermal waters in both Europe and North America, usually only at very moderate temperatures.

Melaniidae

One species of this family, *Melanoides truncatula* Lamarck was taken by us on several occasions in thermal water in the Dutch East Indies. It was present in the overflowing water at Panggaloan Hot Springs and 24 kilometers north of Kotanopan, both in Sumatra, and the Paso Hot Springs of the Northern Celebes. In all cases the temperature of the water was 36° or below.

Viviparidae

A large species of this family, *Viviparus costatus* Quoy and Gaimard, was collected by us in three thermal springs in the Northern Celebes, at temperatures of 37° or less. Following are the localities: Tember Hot Springs, 37°, pH 7.4; Paso Hot Springs, 37°, pH 7.3; spring at Airmadidih, 30°, pH 7.1.

Amphibia

Frogs were obtained in two localities, one in Java and the other in the Celebes, the latter series including tadpoles also. The identifications were made by Mr. Arthur Loveridge of the Museum of Comparative Zoology, who very kindly examined the material.

Rana cancrivora cancrivora Gravenhorst

This species was taken at Tjipanas, Java in water at 40° which is an unusually high temperature for frogs. There were numerous tadpoles in the shallow water of the pool and adults about its edges which immediately dived into the water when disturbed. This temperature is approximately the same as records of 39.2°–41.6° which I have noted for the American *Rana pretiosa* Baird & Girard in Yellowstone Park.

Rana cancrivora verruculosa Roux

This form was very abundant as young and semi-adults in the Langoan hot spring in the Northern Celebes in water of considerably lower temperature (35°, pH 7.7).

Comparison of the Fauna with that of North America

The fauna of North American hot springs is more completely known than that of any other part of the world, sufficiently so to indicate at least in a general way, what types of animal life are represented in the Nearctic thermal fauna. Some groups have unfortunately received little or no attention but among the insects particularly, and to a less extent among the Crustacea, Acarina,

and Mollusca certain families and genera are known to have invaded thermal waters quite generally while others are consistently absent or very poorly represented. Also, as I have previously pointed out, there is a very noticeable similarity between the thermal fauna and that of estuaries, brackish water, and the sea. This is undoubtedly due to some extent to the common presence of dissolved salts in thermal waters and in the sea; however, there are wide differences in the saline components of thermal waters compared to the nearly uniform proportions of specific salts present in oceanic and brackish water. Although sodium chloride exceeds the other salts in some hot springs, the saline constituents of such waters are so varied both in quality and quantity that the only constant similarity is the increase in osmotic pressure resulting from their presence, and the similarity of the several faunas is undoubtedly due directly to this physical factor.

On the basis of the material secured by us in the Dutch East Indies together with the numerous previously published records which are cited earlier in the present account it is possible to compare this fauna with that of the North American continent. Such a comparison is particularly instructive as the two regions are not only widely separated, but one enjoys a temperate climate while the other lies directly in the equatorial belt.

Among insects the order Diptera is represented in North America by seven families: Chironomidae (including Ceratopogonidae), Stratiomyiidae, Culicidae, Tabanidae, Ephydridae, Simuliidae, and Syrphidae, roughly in the order listed both as to number of species, frequency of occurrence, and abundance of individuals. Of these only the first two families listed may be regarded as of very general occurrence in thermal waters. All but the last are known to be represented in East Indian springs, the others in approximately the same order of abundance, except that the first (Chironomidae) are far more abundant than the Stratiomyiidae which are relatively common in North American springs. This great difference may be readily ascribed to the fact that the family as a whole is similarly far more abundant in the Nearctic region than in Malaya. As in North America, Chironomidae have been found to invade water at unusually high temperatures, showing this family to be particularly resistant to excessive heat here also. Thus larvae of a species of *Chironomus*, *C. tentans* in North America has been taken in water at 49° and an unidentified member of the same family was reported at 51°. In Java (*vide antea*) *Dasyhelea tersa* has been found in water at 51°. Various members of this family are frequently found at temperatures of 39° or higher. Other dipterous larvae rarely inhabit water above 35°, with the exception of certain Stratiomyidae which are not infrequently found above 40°, in a couple of instances at 47°. Mosquito larvae seem to be restricted to water below 40°, but it is interesting to note that one American species of *Anopheles*, *A. pseudopunctipennis*, common to both North and South America is frequently found in slightly thermal water. This is true also of at least two Malayan species of *Anopheles*, but no larvae of malarial mosquitoes have been found living in water above 38°.

The coleopterous fauna of East Indian thermal springs appear to be more meagre than that of North America. From the latter region six families, Hydrophilidae, Dytiscidae, Helmidae, Heteroceridae, Gyrinidae, and Haliplidae have been reported, in the order listed with the first two families about equally represented and far outnumbering the others. In the Dutch East Indies only the Hydrophilidae and Dytiscidae are included in the thermal fauna. Nearly all are Hydrophilidae and two genera *Enochrus* and *Berosus* are common to the two regions. This great dissimilarity in the two faunas of thermal water beetles is in keeping with the far greater abundance of aquatic Coleoptera in temperate regions.

Among aquatic Hemiptera, in spite of more fragmentary knowledge more families are known to be represented in East Indian thermal waters than in those of North America. From the latter region six families are known, Corixidae, Notonectidae, Gerridae, Naucoridae, Nepidae, and Belostomatidae. To these must be added from the East Indies four other families, Hebridae, Velliidae, Helotrephidae, and Pleidae, but of these the Helotrephidae do not occur in the New World. The Hemiptera are, however, not highly adapted to high temperatures as none have been reported from water exceeding 39°–40°.

Odonata are known from thermal waters in both regions, both of the suborders, Zygoptera and Anisoptera represented by a few species, usually from water of moderate temperature, only rarely slightly exceeding 40°.

Among other Arthropoda a number of Acarina of several families are included in the thermal fauna. On the basis of very fragmentary knowl-

edge it appears that mites are more abundantly represented in North America. Several species are known to extend into water above 40° and one North American species, *Thermacarus nevadensis* is restricted to hot springs where we have found it very abundantly in water as high as 50.8°. As indicated on a previous page, one aquatic East Indian species has been reported in water at 41°.

Crustaceans of several orders, Amphipoda, Ostracoda, and Isopoda are known from North American hot springs. Certain amphipods are frequently abundant in North American thermal waters although restricted to moderately warm water. None are known so far from East Indian hot springs. In North America we have collected some nine species of Ostracoda in hot springs, several in water at more than 40° and one, *Potamocypris perbrunnea*, at 50°. The latter record indicates that certain ostracods are remarkably well adapted to high temperatures. In the Dutch East Indies we secured no ostracods and only a single species has been taken there in thermal water at 39° as is noted on a previous page (p. 88). It appears therefore that the group is much more poorly represented in the Malayan thermal fauna. On the other hand, several Copepoda are known from hot springs in the East Indies, although none have so far been recorded from such waters in North America.

As indicated earlier in this paper many free-living nematode worms have recently been found in East Indian hot springs, some of them identical or closely related to species from North America whence a series of forms has been reported. Undoubtedly the thermal nematode fauna is abundant and similar the world over, and the same is undoubtedly true among the Protozoa which have been collected extensively in European and East Indian hot springs, but unfortunately not yet investigated in North America.

In spite of the differences just noted, there is a very great similarity in the thermal faunas so far studied in various parts of the world, indicating a homogeneity of composition that shows specific tendencies for certain groups of animals to invade waters of high temperature much more frequently than those of other groups that are obviously unable to do so.

The Structural or Physiological Basis of Heat Susceptibility

Although this matter still rests on a conjectural basis there is available some additional information which supplements the material included in the earlier discussion on the nature of heat susceptibility that forms a part of one of my previous papers (Brues '32).

In my earlier accounts I unfortunately overlooked a paper by Bodine ('23) dealing with the thermal death-point of protozoan cysts. Experimenting with a common ciliate, *Colpoda cucullus*, Bodine found that dried cysts of this animal could resist dry heat as high as 100° C. for periods as long as three days and still remain alive. As he describes the experiments, following exposure to heat, the cysts disclosed living organisms when placed in a proper medium at ordinary temperature. A number of earlier workers had experimented with this and various other soil-inhabiting organisms in connection with the sterilization of soil (cf. Kopeloff and Coleman '17), but only in a very general way.

Bodine's results are certainly surprising and would seem to indicate that encysted Protozoa when highly dessicated are able to withstand heating to points far beyond those that prove immediately lethal to both active and moist encysted individuals. Undoubtedly such behavior is not dependent upon the same factors that determine the heat resistance of non-encysting animals and is analogous at least to the resistance shown by the seeds of some plants.[1] This matter relating to the resistance of animal cysts and the seeds of flowering plants certainly demands further careful investigation before any dogmatic statements can be made. In spite of numerous experiments relating to the sterilization of soil, the destruction of seed-infesting insects, the resistance of spores and encysted organisms, etc., there is still lacking any series of coördinated experiments designed to demonstrate any exact relation of heat susceptibility to desiccation. It may quite likely be found that such conditions of suspended animation where metabolic processes are practically nil are not directly comparable with those of normal metabolic activity.

In a very complete and careful study of the thermal blue-green algae or Myxophyceae of the

[1] A somewhat similar condition has been reported by Mathias ('29) for the eggs of certain phyllopod crustaceans (*Triops cancriformis* and *Branchipus stagnalis*). Heating soil containing the eggs of these animals to temperatures as high as 80° C. failed to prevent the eclosion of nauplii. As the actual temperature of the contained eggs was not determined, these experiments are not so definite as might be desired, but indicate that temperatures above 50° must have likely penetrated to the eggs.

Yellowstone National Park, Copeland ('36) has recently dealt with the temperature relations of this primitive group of plants. On the basis of extensive data collected in the field Copeland found that two species, belonging to different genera, *Phormidium bijahense* Copeland and *Oscillatoria filiformis* Copeland were both growing at a temperature of 85.2° C. This is the highest temperature at which any Myxophyceae were found and as the Yellowstone flora includes a larger number of forms in this group than any other hot springs area, it is probable that these records will not be exceeded in the future. They are indeed, practically identical with previous careful observations made by others and if they are to be exceeded the differences will certainly be negligible in amount. Copeland has not studied the bacteria specifically, but reports the occurrence of living bacteria in these waters at slightly higher temperatures of about 88° C. Thus there are found blue-green algae of several groups and certain unidentified thermophilous bacteria extending to temperatures of between 80° and 88°, figures also in close accord with those noted for bacteria by others.

Between these and other living organisms there is a very wide gap, of approximately 30° C. or more, since no temperatures of over 50°–52° C. have been reported as compatible with life for any animals or for plants other than the bacteria and blue-green algae.[1]

Thus, the more we know about the distribution of living organisms in thermal springs the clearer does it become that their tolerance of high temperatures is not a purely quantitative matter. We find blue-green algae occurring from the ordinary temperatures of ponds and streams over a continuous range to about 85° C. Other plants and animals of all kinds extend continuously in a similar way to about 52° C., but not beyond. With a large and constant gap between these maxima for the two groups of organisms we must admit the occurrence of at least two factors determining heat resistance.

On the basis of present knowledge, it is perhaps idle to speculate concerning the factors that may determine such consistently different reactions. However, at least two plausible theories have already been advanced. Zinsser ('31) dealing with bacteria has suggested that lethal temperatures for specific organisms are determined by the balance between metabolic reactions. As temperatures rise above an optimum, catabolic reactions come to increase more rapidly than anabolic ones and finally lead to death. The same suppositions have been made with reference to the cells of both animals and plants from time to time (Sachs, Höber '25). They have been critically discussed by Bělehrădek ('36) who believes and it seems with reason, that the rapidity of the heat effect is too great to allow time for the accumulation of the postulated toxic metabolic products. Again, we should not expect to find a general agreement in lethal temperatures among animals and some green plants, and a wide divergence between these and other green plants. With reference to the several parts of higher plants there seems to be little difference between the underground and aerial structures. Observations by the writer and others indicate that soil or water surrounding the roots may rise to a maximum of ± 50°–52.5° C. without lethal effect. Wallace and Clum ('37) found that 52.5° C. was the highest temperature to which the leaf tissue of *Verbascum* could rise without inducing irreversible changes that result in the death of the area so affected. They found further that 58°–60° C. regularly kills the leaves of several diverse flowering plants. Rather should there be some correlation between types of metabolism and extent of heat resistance and such obviously does not exist. This is similar to the idea advanced first by Winterstein ('02) of asphyxiation due to a similar unbalance. In its latter form this hypothesis evidently cannot account for the similarity among animals and green plants whose oxygen relations are quite exactly reversed. It might perhaps seem plausible in connection with thermal waters whose oxygen and carbon dioxide tension are both usually low. Both are, however, so highly variable that we cannot on any consistent basis relate them universally to constant phenomena of any kind.

Various workers since the time of Pasteur have noted and commented on the increased resistance shown by seeds and spores to high temperatures

[1] As has been noted on another page, Tuxen ('36) has very recently reported the occurrence of certain insects in thermal springs in Iceland at temperatures as high as 65° C. These observations are so greatly at variance with those of many other workers in this field that they most certainly need careful repetition to make sure that actually living insects are concerned. This is especially true of insect larvae of the family Stratiomyiidae to which these records refer since the overflows in which they live are frequently subject to great temperature changes following sudden shifts in water currents.

and have attempted to relate this to the fact that proteins in general coagulate at higher temperatures when desiccated than when well supplied with water. Assuming that an increased viscosity, disorganization, and coagulation of living protoplasm follow a similar course with reference to rising temperature, the failure of organisms to survive excessive heat has been attributed to irreversible changes in their actual living substance. Obviously, again the generalizations of such an hypothesis recognize no fundamentally different types of response among organisms although they necessarily grant much continuous variation as regards actual heat resistance since it is a matter of common knowledge that such exists.

Concerning all these suppositions there is a maze of experimental data relating to the killing of organisms by heat under practically every manner of conditions, both internal and external. From all this, there has unfortunately emerged no conclusive evidence, nor consensus of opinion as to how, or even whether, phenomena related to protein coagulation or denaturization are concerned.

There is also a mass of observations relating to changes in visible structures in chemically recognizable substances and even in "ultramicroscopical" constitution, of cells and tissues that have been subjected to lethal or near-lethal temperatures. These relate to a great variety of animals and plants and give a complicated picture, with certain features in common. One of these is the rather narrow temperature range at which such changes are quite consistently noted.

The appearance of visible granules has been noted in cells of Protozoa (Schultze '63), in algae (*Spirogyra*) by Lepeschkin ('10) and in other organisms, these appearing at temperatures usually near 45°. Similarly, vacuolization, cytolysis, and modifications of cell form and size are frequently noted at about the same temperature or slightly higher. Changes in the nucleus, commonly involving the chromosomes, are among the first visible cytological changes to occur in the cells of animals when subjected to temperatures above their biokinetic limits. These are to some extent reversible if the exposure to heat is not too prolonged. Thus during mitosis changes may occur resulting in asymetrical divisions or sometimes giving rise to abnormalities or polyploidy. Strangely enough the effect of heat, like that of the drug colchicine is most pronounced in arresting mitosis between the metaphase and telophase.[1]

Finally the visible effects of lethal temperatures are manifest in the mitochondria. I have dealt with these briefly in a previous paper (Brues '28) where the suggestion was made that these minute cytoplasmic objects might quite likely be immediately concerned in determining the upper temperature limits of life. The basis for this idea is the fact that the mitochondria (or chondriosomes) seem to be quite universally highly susceptible to heat, being usually destroyed or permanently damaged at temperatures of between 46°–52° C. They appear to be of regular occurrence in the cells of animals including the germ cells, and those of all except the lowest plants. That mitochondria occur in all animals cannot be definitely stated, but their presence is so widespread that there is no reason to doubt their universal occurrence. The same is true of the green plants that contain chloroplastids, in fact the plastids of such plants appear to owe their origin to mitochondria.

It has recently been questioned by Sorokin ('37) whether the mitochondria and plastids of the higher plants are really identical structures. Although both are extremely similar in appearance and are self-perpetuating by division, she has shown that they react differently in the living state to Janus green B, the plastids failing to take up this stain, although the mitochondria are stained readily. Since, however, the process of staining is to some extent dependent upon hydrogen ion concentration, her contention, although plausible, cannot be considered as finally proven. In any case the distinction between plastids and mitochondria does not indicate that they are in any sense fundamentally different structures, even though not identical.

Mitochondria have also been found in fungi. They do not occur, however, in the blue-green algae, which lack also chloroplastids and they are absent so far as is known in bacteria. The exact nature of the mitochondria is of course not well understood, mainly on account of their minute size, coupled with the fact that they are not demonstrated by popular methods of cytological study. That they are ever essential to life is sometimes questioned, but in the groups where they occur it is generally believed that they must play a definite role in metabolism, probably in

[1] cf. Kemp. & Juul, '31; Lambert & Hanes, '13; and many other papers cited by Bělehrădek '35.

cellular respiration or oxidation, at least in animals.[1]

In his paper on Myxophyceae, Copeland ('36) has raised the objection that temperatures lethal for some animals, *e.g.*, certain marine coelenterates and echinoderms, are much lower than those at which the mitochondria usually suffer irreversible changes. Such is most certainly correct and it is generally true that the heat susceptibility of marine animals is usually much greater than that of fresh-water and terrestrial forms. As a matter of fact among the long series of animals that occur in hot springs there is great variation among different forms and many certainly never extend into water above 30° or thereabouts. I certainly should not attempt to apply to such organisms any general theory concerning the deleterious effects of heat. Many of them are obviously handicapped by respiratory apparatus incapable of functioning at tensions of oxygen that are quite sufficient for other organisms. Again there are animals, *e.g.*, the primitive insect *Grylloblatta*, that normally lives at temperatures only slightly above freezing and succumbs when subjected to those necessary for the activity of related insects. Various "snow" insects are similar in this respect. Moreover, we have positive proof in at least one case that races of the same species may exhibit distinctly different maxima of heat tolerance. Banta and Wood ('28) have described a thermal race of cladoceran Crustacea which arose as a result of sexual reproduction in a strain of *Daphnia longispina* which Professor Banta had previously under continuous observation in the laboratory for fourteen years through 363 parthenogenetic generations. The normal temperature for growth and survival of these animals is ± 20° C. and they will not survive at 27° C. The thermal race arose as a mutation and shows optimum growth and survival at a temperature of 27° C., the lethal point for the parent stock. Rapid heating of the two races results in death at 38° for the normal stock and at 43° for the thermal one. The maximum growth temperatures are 26° and 32° respectively. It is perfectly obvious in this case that we are not dealing with any general characteristic of protoplasm, but with the appearance of a recessive mutation which showed itself after sexual reproduction and was later maintained through the succeeding parthenogenetic ones. In either case the heat resistance is not high, compared with many other arthropods, and can hardly be considered as having a direct bearing on the much higher critical point of ± 50° C.

It does appear, however, that the very consistent reactions of the most diverse animals and plants in approaching toward a narrow range of lethal temperatures is due to some fundamental peculiarity either in the constitution of their tissues or in the operation of their metabolic processes. So far the only recognizable difference between the two series, one approaching to ± 50° C. and the other to ± 85° C. is the presence of mitochondria in one and their absence in the other. Whether the mitochondria are metabolically active structures or whether they only indicate some type of metabolic function, such as oxidation, that is associated with their presence cannot be stated with assurance.

It may be argued that since nuclear changes commonly appear in the cells of animals when subjected to lethal or sublethal temperatures, that we must look to the nucleus for the susceptible structures. Such changes as have been observed in both animals and plants are by no means uniform but they occur experimentally at temperatures quite similar to those which affect the mitochondria. According to various observers they consist frequently in a visible disorganization of the nucleus sometimes associated with its fragmentation or coagulation and the disappearance of the contained chromatic substance. The blue-green algae lack nuclei also, so that they are in this respect different from animals and other plants. Concerning the bacteria it cannot be stated that they either possess or lack nuclei directly comparable with those of other organisms. They certainly contain substances which indicate the presence of some structural or physiological homologue of the differentiated nucleus. It is likewise difficult to say whether bacteria may contain mitochondria. So far as we know, they do not and I believe there is no evidence that we should attribute to them any homologous structures. If these latter statements represent correctly the status of the bacteria it is clear that it is the mitochondria and not the nucleus which form the structural dif-

[1] The literature on temperature and mitochondria has been briefly summarized by Bělehrádek ('35) and the reader will find other papers relating to them with reference to the present discussion cited in my 1928 paper, to which the following may be added as particularly relevant: Famin, '31; Heilbrunn, '28; Kemp & Juul, '31; Lewis & Lewis, '15; Polichard, '12; Polichard & Mangenot, '22; Schultze, '63; Winterstein, '02.

ference between the types of organisms of high and low thermal resistance.

There remains the possibility that heat susceptibility is a general physiological phenomenon relating to protoplasm and metabolism as such and not associated with any definite structural constitution in the organisms concerned. The improbability of such a supposition is I believe clearly shown by the grouping of living organisms into the two quite clearly distinct categories having widely separated thresholds or ranges of heat susceptibility.

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CHANG PO-TUAN

Picture reproduced from the *Lieh hsien ch'üan chuan.* In his hand the jade flower (*Hydrangea*) which he brought back from the spirit journey to *Yang-chou.*

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